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PROPERTIES OF POWDER METALLURGY STEEL FORGINGS

A. Crowson, R. J. Grandzol, and F. E. Anderson

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 The effects of processing variables on the mechanical properties of heat-treated powder metallurgy (P/M) steel forgings were determined. Three powders, AISI 4600 and modified AISI 4600 powders blended with graphite to yield 4640 composition, and AISI 4650 powder, were compacted into preforms and hot forged in a warm, closed die. Variables studied were preform density, method of lubrication, preform sintering (time, temperature and atmosphere), forging pressure (20 and 40 tsi) and temperature (1850°F, 2000°F and 2200°F), and forging ratio
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(0.85 and 0.95). Relationships between interconnected porosity and total porosity for the various preform densities were determined. High density compacts required higher sintering temperatures due to the restricted mobility of the reducing gases in the pores. Die wall lubrication was comparable to admixed lubrication, and it simplified powder mixing and preform sintering operations. Forgings with densities from 99 to 99.8 percent of theoretical density were attained with a forging pressure of 20 and 40 tsi and preform temperatures of 2000°F and above. At forging conditions which resulted in forgings with acceptable mechanical properties, complete die fill was accomplished at a forging ratio of 0.95, whereas incomplete die fill resulted at a forging ratio of 0.85. The response of P/M forgings to heat treatment was comparable to that for wrought materials, and the resultant tensile and yield strengths were equivalent to the strength values described for wrought 4640 steel in AMS specification 6317B. In addition, ductility and impact properties of P/M forgings with near theoretical density (99.5+ percent) were comparable to bar stock forgings. (U) (Crowson, A., Grandzol, R. J., and Anderson, F. E.)
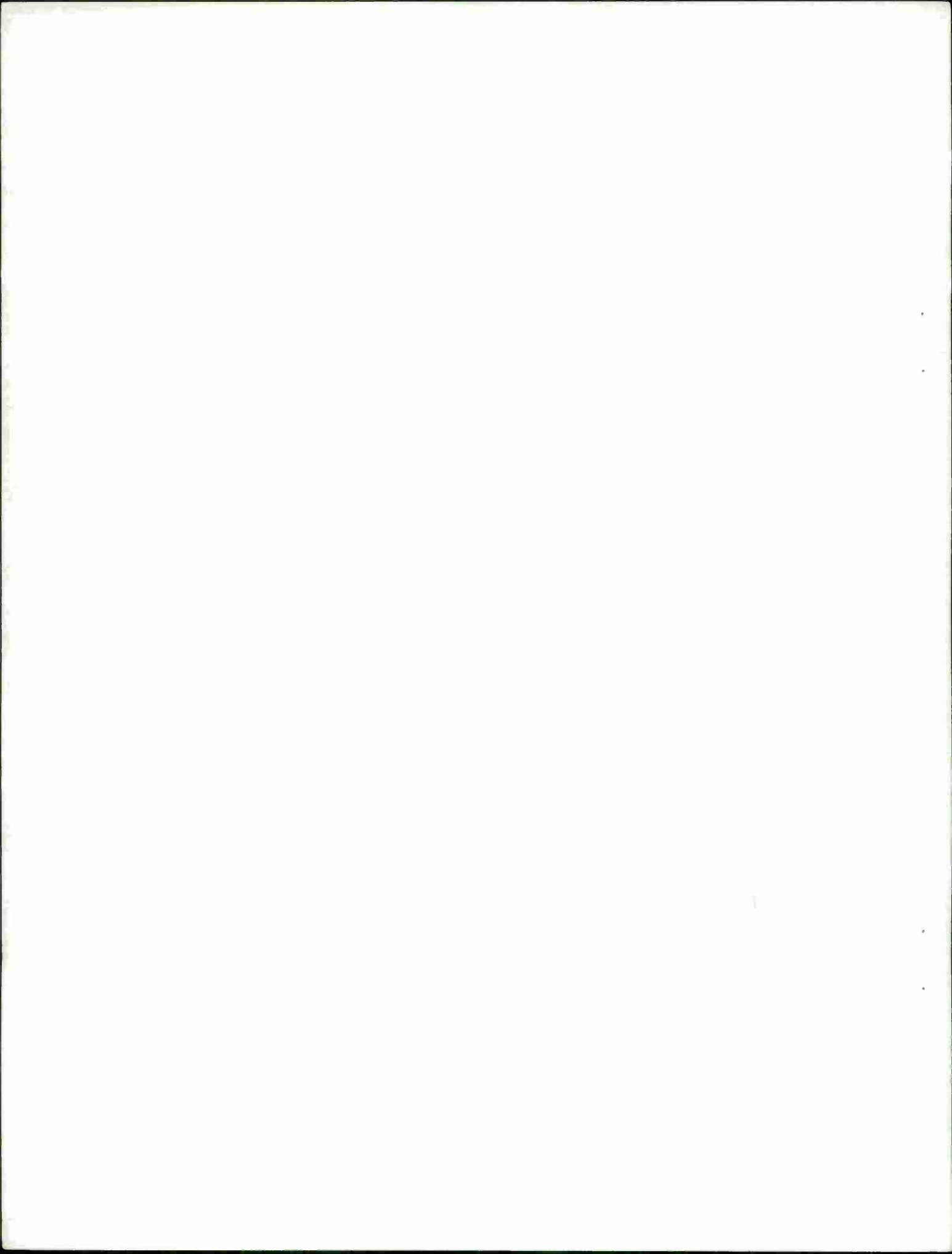
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INTRODUCTION

The manufacture of engineering components by the usual powder metal-lurgy (P/M) approach of pressing and sintering produces parts which have lower physical and mechanical properties than wrought or cast materials of the same composition. The lower properties are attributed to the high residual porosity.[1,2,3] Recently, much emphasis has been placed on in-creasing the density and mechanical properties of P/M parts by the added operation of hot forging. Densities of 96 to 100 percent of theoretical have been obtained, permitting P/M hot-forged components to be substituted for wrought components, or for castings.[4,5]

The successful application of the powder metallurgy forging process to ordnance components offers substantial benefits. Primary cost advan-tages over the conventional processes lie in more efficient material utilization and the significant reduction or complete elimination of finish machining steps. Thus, costs in the production of many load-bearing components which are conventionally forged have been reduced by 25-50 percent.[5,6,7]

The effects of the processing variables on the mechanical properties of heat-treatable steel P/M parts have not yet been adequately determined. There has been a lack of published data in this area, partly due to the proprietary nature of much of the advanced work currently in progress. Also, the work which has been published reflects the use of a variety of specialized evaluation procedures and customized fabrication techniques for individual parts which cannot easily be adapted for universal applica-tion.

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1 Knoop, W. V., "Furnace Heating vs. Induction Heating of P/M Preforms", 1970 Fall Powder Metallurgy Conference Proceedings, October 1970, pp. 104-118.

2 Kaufman, S.M., and Mocarski, S., "The Effects of Small Amounts of Resi-dual Porosity on the Mechanical Properties of P/M Forgings," 1971 Fall Powder Metallurgy Conference.Proceedings, October 1971, pp. 125-136.

3 Cull, G.W., "Mechanical and Metallurgical Properties of Powder Forgings," Powder Metallurgy, Vol. 13, No. 26, 1970, pp. 156-164.

4 Huseky, R.A., and Scheil, M.A., "Forgings From P/M Preforms," Modern Developments in Powder Metallurgy, Henry Hausner, Editor, Vol. 4, Plenum Press, New York, 1971, pp. 395-413.

5 Gustafen, D.A., "HD:P/M = High Density Parts via P/M Techniques," Metal Progress, April 1972, pp. 49-58.

6 Lally, F. T., and Toth, I.J., "Forged Metal Powder Gears," Technical Report No. 11960, September 1974.

7 Lally, F.T., Toth, I.J., and DiBenedetto, J., "Forged Metal Powder Products," SWERR-TR-72-51, August 1972.

The objective of a current program in our laboratory is to develop capabilities in P/M forging which will meet the unique requirements of military applications. This study involved establishing a property baseline on the effects of processing variables on the physical and mechanical properties of heat treated P/M steel forgings. Variables studied included lubricant, preform sintering (time, temperature, and atmosphere), forging pressures and temperatures, and forging ratios. Determination of the effect of these variables were limited to commercially available prealloyed steel powders. Steel powders blended from the basic elemental powders were not evaluated due to the inhomogeneities and impurities resulting from such mixtures.

PROCEDURE

Three nominal 4600 steel powders produced by commercial manufacturers were selected for study. The chemical analyses of the powders appear in Table I. Two of the powders, Glidden 4600 and 4650†, had standard AISI compositions; the A. O. Smith EMP 4600†† had a composition which was modified (lower manganese, higher molybdenum) ostensibly to promote processing characteristics. Flake graphite was added to the 4600 powders to obtain the 0.4 percent carbon content. The powders were characterized according to size and size distributions (ASTM B-214-56), apparent density (ASTM B-212-48), and flow rate (ASTM B-213-48). Individual particles were evaluated by scanning electron microscopy and metallography.

Two methods of lubrication, admixed and die wall, were used. Admixed lubrication involved blending the powdered lubricant (1 percent Acrawax*) with the metal powder; no die wall lubrication was then required. Die wall lubrication consisted of spraying the die walls and punch with graphite or Acrawax lubricant.

The powders were compacted with the desired lubricant (admixed or die-wall) to densities in the range of 5.6 to 7.1 g/cm^3 using the die assembly shown in Figure 1. Density-compaction pressure relationships were developed for the powders. Densities were determined according to the ASTM B-328-60 test procedure for porous metal parts. This procedure also allows the calculation of the fraction of the total porosity which is interconnected. A "green strength" of the powder compacts was determined using a three-point bend test analogous to that described in ASTM B-312-58T.

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† The powder as designated is a product of Glidden Metals, SCM Corporation.

††The powder as designated is a product of A. O. Smith and Inland Inc.

* Product of Glyco Chemical Company.

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TABLE I

CHEMICAL ANALYSES OF 4600 PREALLOYED POWDERS

Element	Specification	A. O. Smith EMP 4600(1)*	A. O. Smith EMP 4600(2)	Glidden 4600	Glidden 4650
Carbon	---	0.00	---	0.04	0.56
Nickel	1.65-2.00	1.45	1.77	1.74	1.74
Molybdenum	0.2-0.3	0.62	0.48	0.26	0.23
Manganese	0.6-0.8	0.19	0.23	0.40	0.51
Copper	---	0.04	0.05	0.03	0.04
Chromium	---	0.07	0.05	0.04	0.10
Phosphorus	0.04 max	0.01	<0.01	0.01	0.01
Sulfur	0.04 max	0.03	0.02	0.03	0.02
Silicon	0.2-0.34	0.02	0.07	0.28	0.42
Oxygen	---	0.170	0.152	0.291	0.263

*Work was initiated with this powder. Although nickel content was low, the preliminary results from this powder have general applicability.
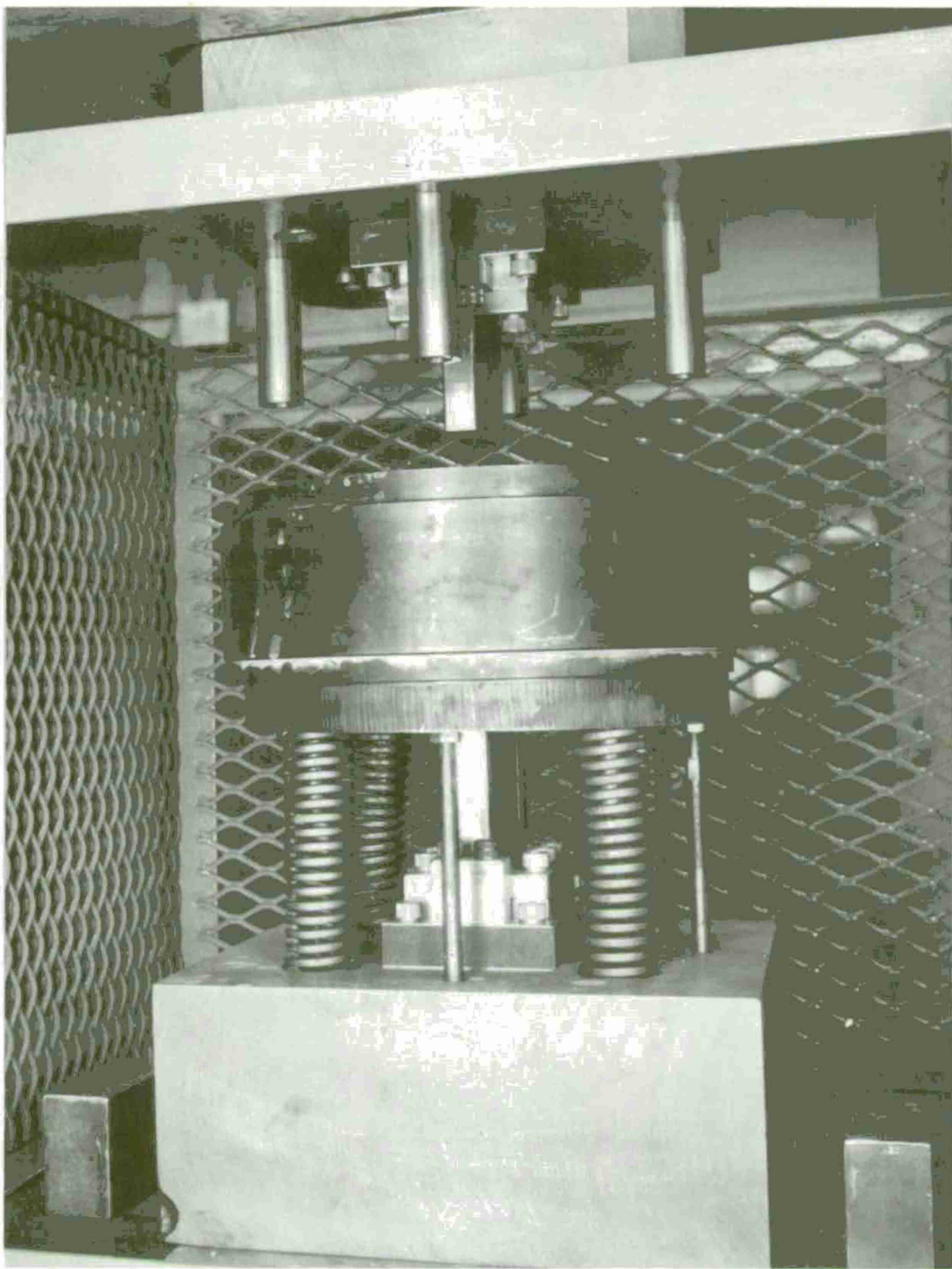
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FIGURE 1   Compaction Tooling

The dimensions of the preform are shown in Figure 2a. Some of the preforms were machined after the sintering operation to allow for more lateral flow during the forging operation. Figure 2b shows the machined preform. The flange is used at the end of the preform to help center the preform prior to forging. The forging appears in Figure 2c. Forging ratio, the ratio of the preform plan area to the forging plan area, describes the extent of lateral deformation of the preforms. Two ratios, 0.95 (as pressed) and 0.85 (machined) were studied.

The forging studies were conducted in two phases: (1) an initial phase, using non sintered and vacuum sintered preforms and (2) a secondary phase, using preforms sintered in a hydrogen-methane atmosphere.

In the initial phase, preforms of EMP 4600 powder were forged at three pressures (20, 29, and 40 tsi) at approximately 2000°F. Three sets of preforms at three different preform densities; 5.75 g/cm^3 (73 percent of the theoretical density), 6.25 g/cm^3 (80 percent), and 6.90 g/cm^3 (88 percent) were processed. The first set of preforms was preheated only for 5 minutes before forging. The second set was sintered in vacuum at 2050°F for 1 hour and allowed to furnace cool. This set also received a 5-minute preheat before forging. The third set received the same sintering treatment as the second and was machined to the configuration shown in Figure 2b. This set was also preheated for 5 minutes before forging. All preforms were graphite coated and preheated in a small muffle furnace in an argon atmosphere.

In the second phase of the forging studies, preforms of the three commercial powders were forged. Two forging pressures (20 and 40 tsi) and three forging temperatures (1850°F, 2000°F, and 2200°F) were used. All preforms were sintered for an hour at 2050°F in a 99:1 hydrogen-methane atmosphere. The preforms were then brought to forging temperatures in a flowing hydrogen-methane atmosphere and rapidly transferred to the forging dies and forged. The dies were preheated to 450-500°F by gas. All forging temperatures and pressures used were based on previous P/M forging literature data.

The forged specimens were heat treated as follows: austenitized for 1/2 hour at 1550°F, oil quenched; tempered for 1 hour at 1100°F and water quenched. The heat-treated forgings were analyzed for density, grain size, decarburization, elongation, yield and tensile strengths, carbon and oxygen content, and Charpy impact energy. Mechanical properties were compared to those required by Military Specification MIL-F-45961.

RESULTS AND DISCUSSION

The powder characteristics of the three powders used are given in Table 2. Typical bimodal distributions were found to be present. Apparent densities ranged from 2.96-3.15 g/cm^3. Flow rates ranged from 23.8 to 27.4 seconds for the various powders.

Scanning electron microscope (SEM) examinations (Figure 3) show a distribution of shapes - spheroidal and "popcorny". Figure 4 shows the

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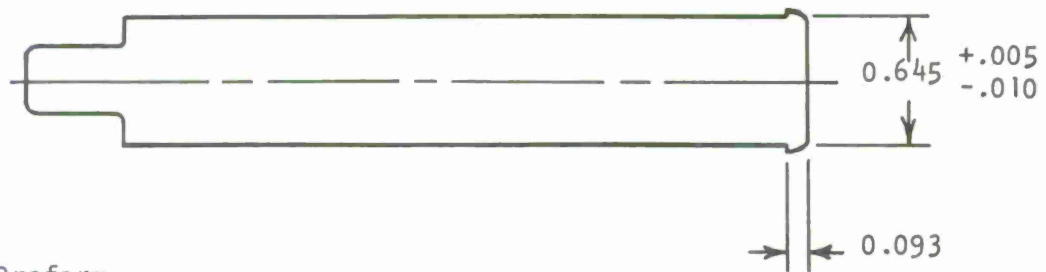
a. Preform

b. Machined Preform

c. Forging

FIGURE 2   Shapes of Preforms and Forging
                  (Dimensions are in inches)

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TABLE 2

POWDER CHARACTERISTICS

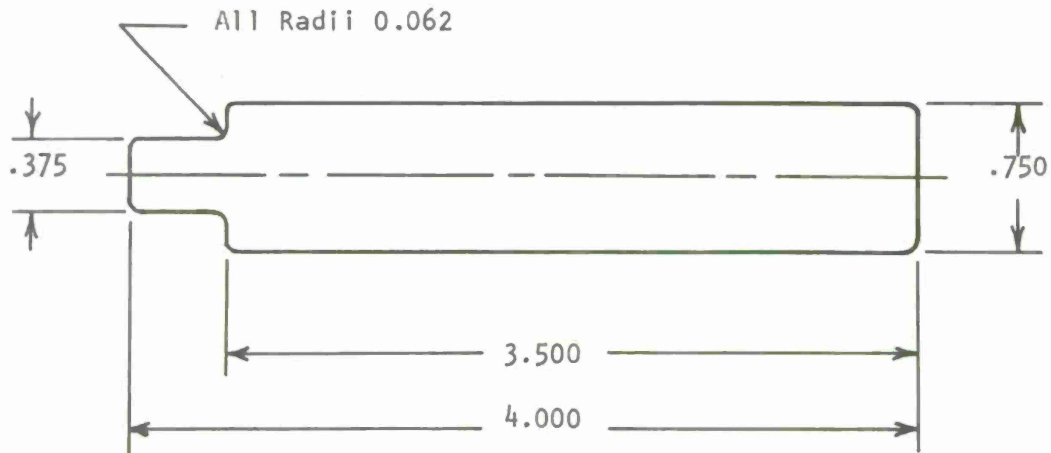| U.S. Screen Size	Sieve Analyses, wt,%			
	A. O. Smith EMP 4600(1)	A. O. Smith EMP 4600(2)	Glidden 4600	Glidden 4650
+ 80 (180μ)	---	0.1	---	0.1
- 80 + 100	3.4	4.5	1.7	0.4
- 100 + 140	11.4	14.5	11.3	7.0
- 140 + 200	19.8	23.4	21.2	17.5
-200 + 230	6.7	7.5	6.1	5.5
- 230 + 325	18.2	18.7	17.4	17.6
- 325 (44μ)	40.5	31.3	42.1	51.8
Apparent density (g/cm³)	2.96	2.99	3.08	3.15
Flow rate (sec.)	23.8	25.8	27.4	25.5
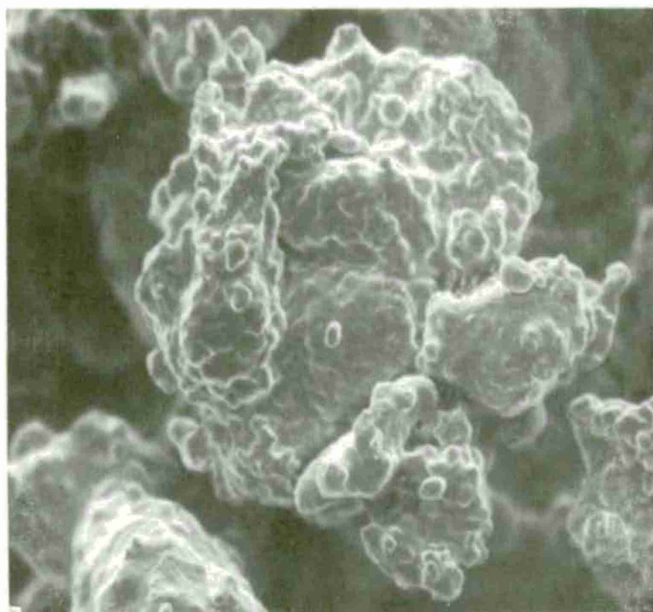
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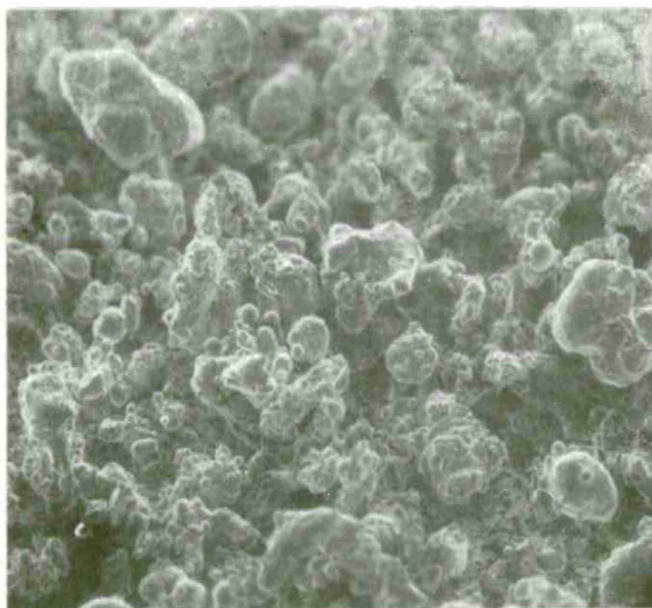
80X

FIGURE 3   Typical Particle Shapes of 4600 Powders (SEM)

Nital Etch   400X

A. O. Smith EMP 4600 (1)

Nital Etch   400X

Glidden 4650

FIGURE 4   Microstructures of 4600 and 4650 Prealloyed Powders

microstructure of the A. O. Smith 4600 powder (which is typical of the other 4600 alloys) and of the Glidden 4650 powder. Grain size within the individual particles was generally uniform at ASTM No. 12.

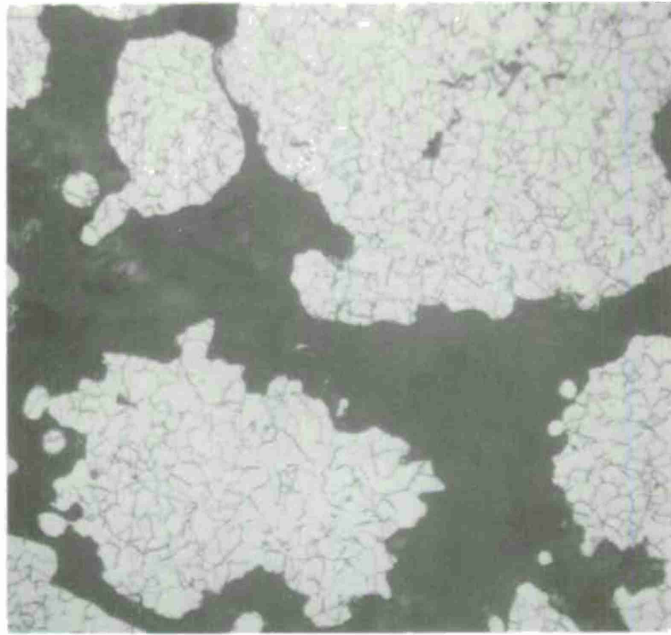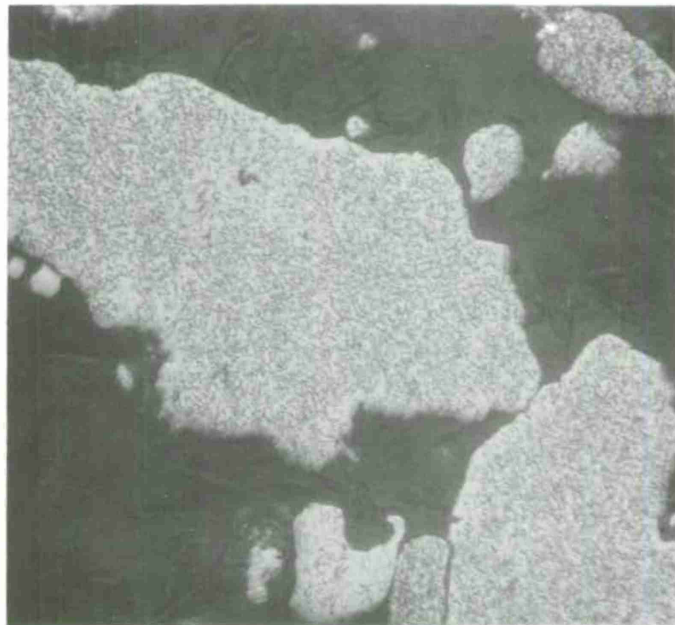In general, the raw material characterization revealed only minor variations in the starting materials. The significance of these variables could not be assessed early in the program. The chief value of this type of data, however, is to ensure reproducibility of the raw material during later stages of this program and subsequent programs.

The density-compaction pressure relationship is shown in Figure 5 for the EMP 4600 powder. The relationship is typical of the other powders also, and is described by the empirical equation

$$\rho = aP_c{}^b$$

where ρ is the compact density, P_c is the compaction pressure, and "a" and "b" are constants. Values of "a" and "b" for all powders studied are given in Table 3. Two powder blend types are represented: 4600 powder with 0.5 percent admixed graphite (4650 was as-received), and the powders with 0.5 percent admixed graphite plus 1 percent admixed Acrawax.

The relationship between interconnected porosity and total porosity is shown in Figure 6. Total porosity is the sum of the amount of interconnected porosity and isolated porosity. As shown in Figure 6, the isolated porosity tends to decrease with increasing interconnected porosity. Therefore, with high density compacts (more isolated porosity than interconnected porosity), this condition creates the need for higher sintering temperatures, since the mobility of the reducing gases in the pores is restricted.

The effect of admixed lubrication and die wall lubrication was evaluated in terms of the "green strength", or the transverse rupture strength of the preforms. Comparison of the data showed that over the green density range of 5.6 to 7.1 g/cm^3, the preforms with die wall lubrication were stronger than the preforms with admixed lubrication by a factor of 2 to 3. For example, at 7.0 g/cm^3, the green strength for the preform compacted with die wall lubricant was 3300 psi as compared to 1450 psi for the preform compacted with Acrawax. This lowering of green strength occurs because the Acrawax interferes with the mechanical interlocking among the particles.

Conditions and results of the initial forging phase are presented in Table 4. From the results obtained, forged density appeared to be sensitive to forging ratio; i.e., the greater the lateral deformation, the greater is the densification. A forging ratio of 0.95 is characteristic of a process called the "minimum deformation" process by its

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$$\rho = 2.38 \, P_c{}^{.238}$$
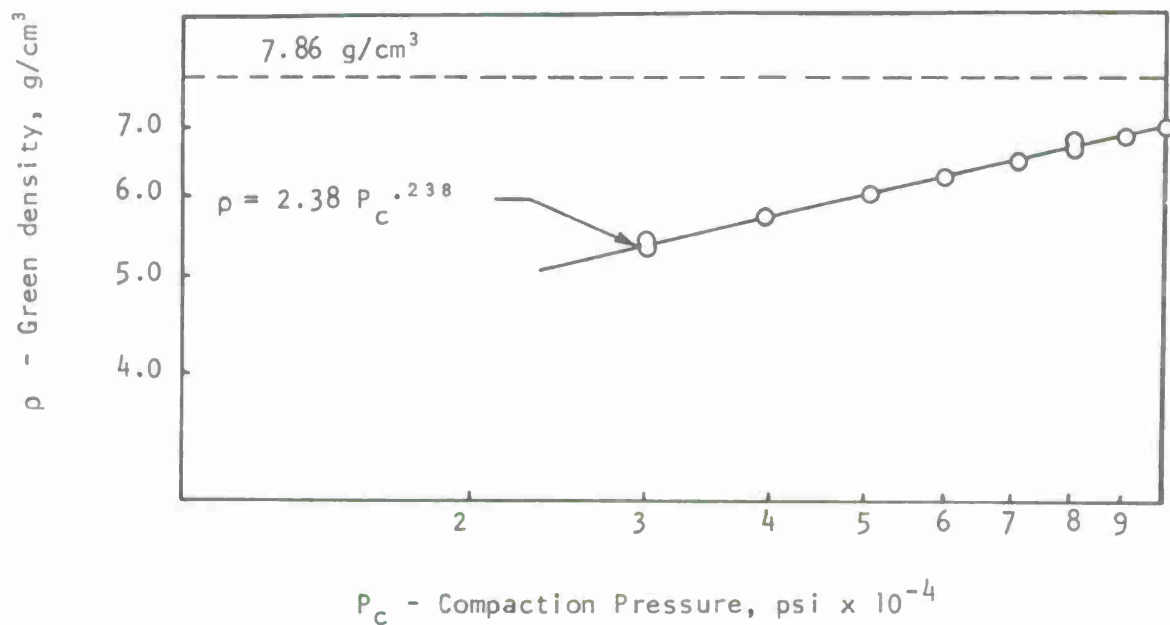
FIGURE 5　　　　　Compactibility of EMP 4600 (1) Powder

TABLE 3

COMPACTION EQUATION CONSTANTS

Powder	a	b
EMP 4600(1)	2.38	0.24
EMP 4600(2)	2.66	0.21
4600	2.59	0.21
4650	2.03	0.25
EMP 4600(2) A*	3.08	0.18
4600A	3.25	0.16
4650A	2.72	0.19

A* - designates powders with 1% Acrawax admixed

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% Porosity = 100% - % of theoretical density

FIGURE 6   Total and Interconnected Porosity

TABLE 4

PHASE I FORGING RESULTS

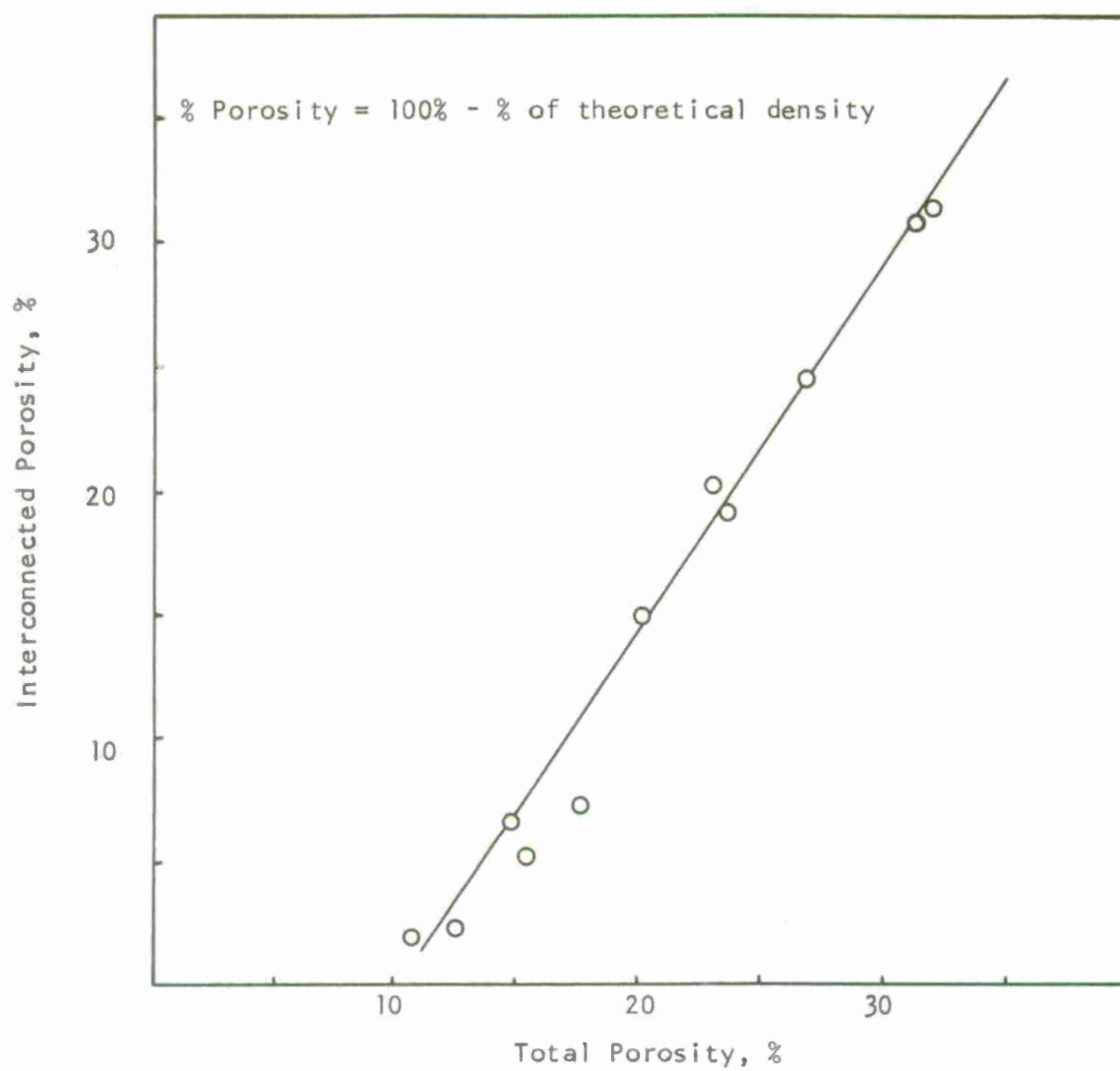| No.	Specimen Condition	Forging Pressure, tsi	Forging Temp. °F	Density g/cm³	99.5%+	99.0%+	Tensile Strength, psi	V-Notch Charpy Impact, ft-lb.
1	R-L+	20	1920	7.71				
2	R-M	20	1940	7.78		*		
3	R-M	20	1960	7.61				
4	R-H	20	1940	7.75				
5	R-L	28	1980	7.83	*	*		6
6	R-L	40	1900	7.79		*		
7	R-M	40	2010	7.77				8
8	R-M	40	2030	7.77				6
9	R-H	40	2000	7.83	*	*	130,000	
10	H-L	20	1960	7.16				12
11	H-M	20	1990	7.81		*		10
12	H-M	20	1980	7.78		*		10
13	H-H	20	1940	7.76				8
14	H-L	28	1980	7.82	*	*		8
15	H-M	40	2020	7.87	*	*	156,000	
16	H-M	40	1850	7.81		*		
17	H-H	40	2020	7.80		*	168,000	
18	H-M*	40	1650	7.70				
19	M-L	20	2000	7.78		*		12
20	M-M	20	1950	7.83	*	*		
21	M-M	20	1980	7.75				
22	M-H	20	----	7.83	*	*		11
23	M-L	28	1980	7.82	*	*		10
24	M-L	40	2010	7.81		*	160,000	
25	M-M	40	2010	7.84	*	*	156,000	
26	M-H	40	2030	7.81		*		
27	M-H	40	1980	7.84	*	*	158,000	
28	M-M*	40	1670	7.82	*	*		

+ First Letter

   R - preheated only (F=0.95)

   H - Sintered (F=0.95)

   M - sintered & machined (F=0.85)

Second Letter

   L - low density (73%)

   M - medium density (80%)

   H - high density (88%)

* lower temperature trials

developers at TRW, Inc.[7] The "minimum deformation" process led to complete die fill by the forgings, whereas the smaller forging ratio of 0.85 tended to produce forgings with incomplete die fill as manifested by rounded edges. This occurs due to insufficient lateral flow occurring during the forging operation. Therefore, more work should be done to arrive at conditions of full die fill with optimum densities. Table 4 also shows that: (1) preform density did not affect forged density and (2) sintering the preform affected the forging density substantially (as evidenced by comparison of Nos. 2 and 3, and 20 and 21 in Table 4).

Surface finish was affected by two factors: (1) amount of lubrication and (2) rapid cooling of the preform surfaces in contact with the die. Too much lubricant led to a crazed surface finish on the forging. Machine marks, clearly visible on the surface of the low forging ratio specimens, indicated a resistance to deformation due to cooling of the preform surface.

Specimens sectioned and etched showed that decarburization occurred in some instances to a depth of 0.100-inch. Decarburization was present to the same extent in both the preheated-only and sintered-and-preheated specimens, leading to the conclusion that decarburization occurred during the preheat operation. Figures 7a and 7b show that the grain size of the decarburized area is approximately ASTM No. 10. For the preheated-only forgings, a ferritic microstructure was observed throughout with a measured hardness of $\sim R_c 20$. The sintered-and-preheated forgings, on the other hand, had a ferritic microstructure at the surface ($\sim R_c 20$) and a tempered martensite microstructure at the center (R_c 30-33). The reason for the low hardness in the preheated-only forging was apparently due to incomplete carbon (graphite) homogenization.

The tensile property data obtained from selected specimens is shown in Table 5. Other than the obviously weak properties of specimen No. 9, due to lack of a sintering step, forging ratio and preform density do not influence tensile strength. The sintering step is important for two reasons (besides the reduction of harmful oxides remaining in the preform): (1) it is conducive to carbon diffusion and homogenization and (2) it forms interparticulate bonds which contribute to the strength of the forged product.

V-notch Charpy impact results of Phase I presented in Table 4 , show that the only discernible influence on the difference in impact energies is the effect of sintering. The oxides remaining in the preforms that were not sintered in vacuum have a dramatic, detrimental effect on impact strength. Oxygen content of the powder was approximately 1700 ppm, that of the preheated specimens was 1450 ppm, and that of the sintered and forged specimens was 1050 ppm. These data show that, although the specimens were sintered in vacuum and preheated in an argon atmosphere, some reduction of the oxides occurred (by the admixed graphite). This is evidenced from the reduction in carbon content found in sintered specimens (0.36 percent) as compared with preheated-only specimens (0.41 percent).

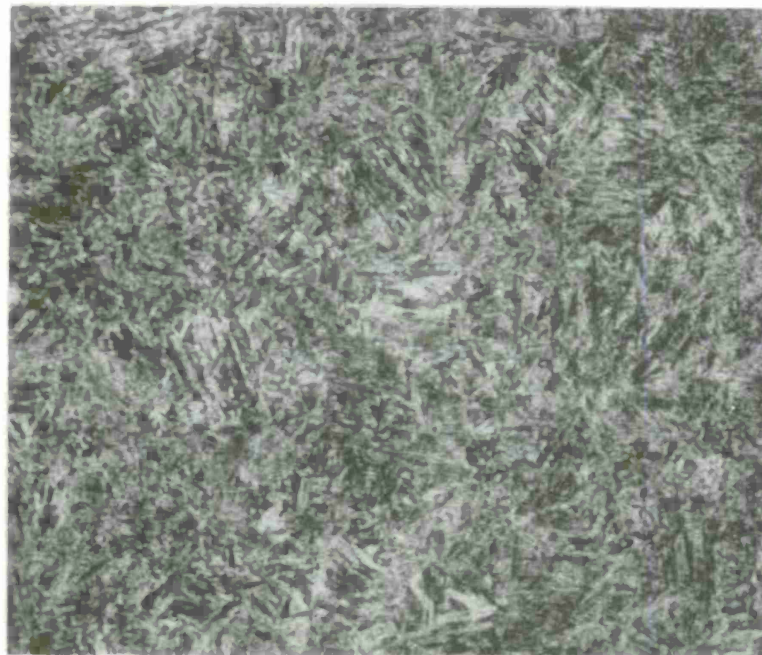7 Lally, F. T., Toth, I. J., and DiBenedetto, J., "Forged Metal Powder Products," SWERR-TR-72-51, August 1972.
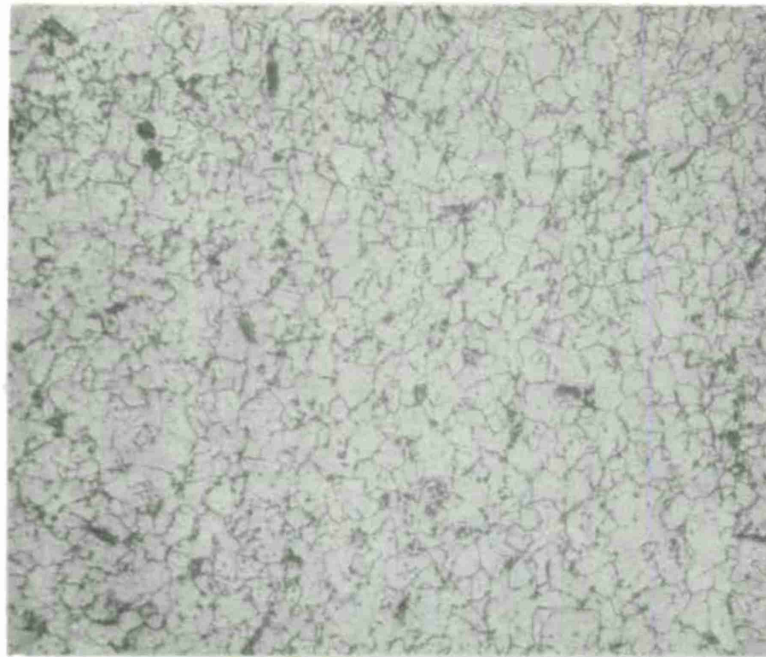
Nital Etch   400X

a. Surface

Nital Etch   400X

b. Center

FIGURE 7   Decarburization, Grain Size, and Microstructure
              of Heat Treated P/M 4640 Forgings

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TABLE 5

TENSILE TEST RESULTS OF PHASE I FORGINGS

No.	Condition	Density g/cm^3	Hardness[1] R_c	Yield Str.,[2] psi	Tensile Str., psi	Elongation %	Reduction in Area, %
9	R-H	7.83	<20	107,000	130,000	11	27
15	H-M	7.87	30	144,000	156,000	13	40
17	H-H	7.80	32	159,000	168,000	10	31
24	M-L	7.81	32	152,000	160,000	12	35
25	M-M	7.84	30	147,000	156,000	13	40
27	M-H	7.84	32	147,000	158,000	12	43

1 - An average of at least 11 readings on the tensile specimen near the threads and on the gage.

2 - 0.2% Offset; Modulus of elasticity = 30×16^6 psi

Figure 8 is an SEM fractograph of the Charpy fracture surface of specimen No. 8. Areas of microvoid coalescence are visible and are believed to be present at the powder particle interfaces. This condition is probably responsible for the observed intergranular fracture surfaces.

Results of the second phase of this forging study are shown in Figures 9-13. All forgings from Glidden 4650 powder showed cracking after quenching (Figure 9). Most cracks were confined to the surface and did not affect the final test piece. No other material was susceptible to cracking. Other than the higher oxygen content for the Glidden powder, no other factor could be correlated with the result.

The effect of pressure and temperature on specimen density is shown in Figure 10. EMP 4600 powder densifies far more easily than the other powders tested, and is influenced relatively little by forging pressure and temperature when the temperature exceeds 2000°F. The preforms of Glidden 4600 and 4650 were relatively difficult to press and were significantly aided by increased forging temperatures.

The ultimate tensile strengths and yield strengths as compared to densities of the forged samples are given in Figure 11. The tensile properties measured in the heat treated condition were found to be density-dependent. Minimum ultimate tensile strength and yield strength for wrought 4640 is shown for comparison. The tensile and yield properties observed for the high density forgings is attributed to the uniformity and the fineness of the grain structure.

Elongation and reduction of area of the P/M forgings are presented in Figure 12. Ductility values show no relation to the forging temperature or pressure other than a strong dependence on forged density. Equivalent ductility for wrought materials requires densities of 99.5 percent or better.

The impact strength (Figure 13) is, as expected, strongly dependent on forged density. As theoretical density is approached, a dramatic increase in impact strength is obtained. Impact strength values were found also to be strongly dependent in all cases on the oxygen content with impact strengths higher than 25 ft.-lbs. obtainable when oxygen content was 300 ppm or less.

CONCLUSION

The results of the forging study have shown that the mechanical properties of P/M forgings can be competitive with those of wrought materials. The response of P/M forgings to heat treatment is comparable to that of wrought materials and the resultant tensile and yield strengths meet AMS specifications 6317B set up for wrought 4640 steel.[7]

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[7] Lally, F.T., Toth, I.J., and DiBenedetto, J., "Forged Metal Powder Products," SWERR-TR-72-51, August 1972.
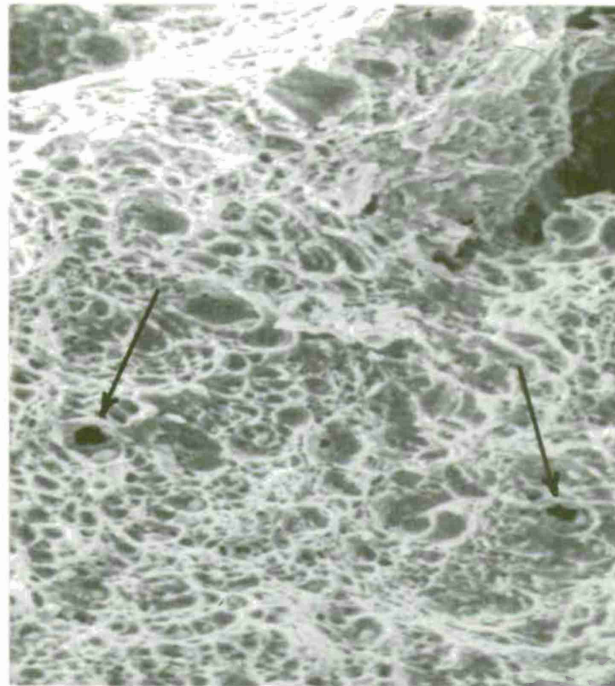
800X

FIGURE 8   Charpy Impact Fracture Surface

The arrows indicate areas of microvoid coalescence

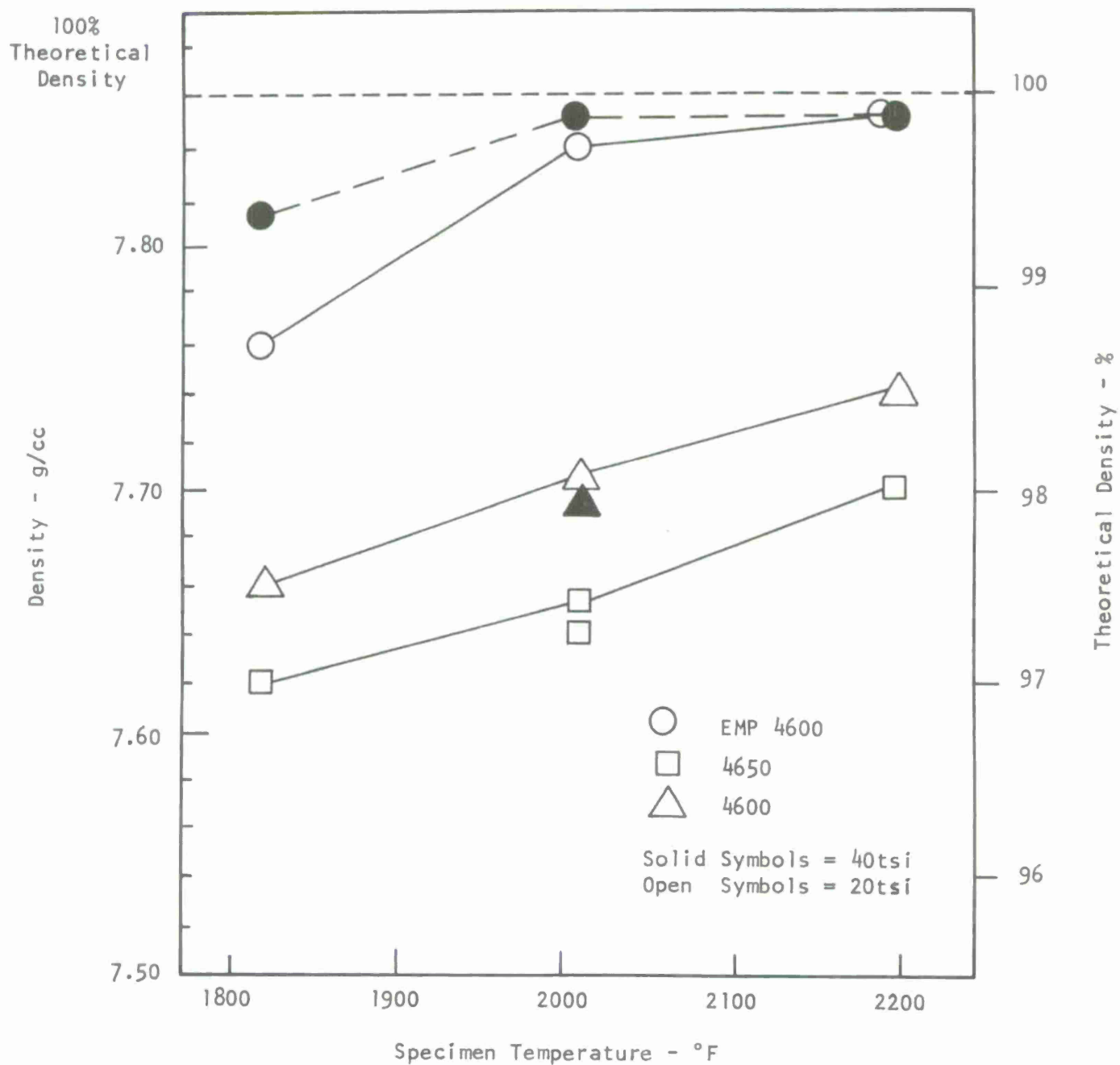FIGURE 9   Forged Preforms of 4650 Steel After Quench

FIGURE 10   Minimum Deformation Forging Pressure, Temperature
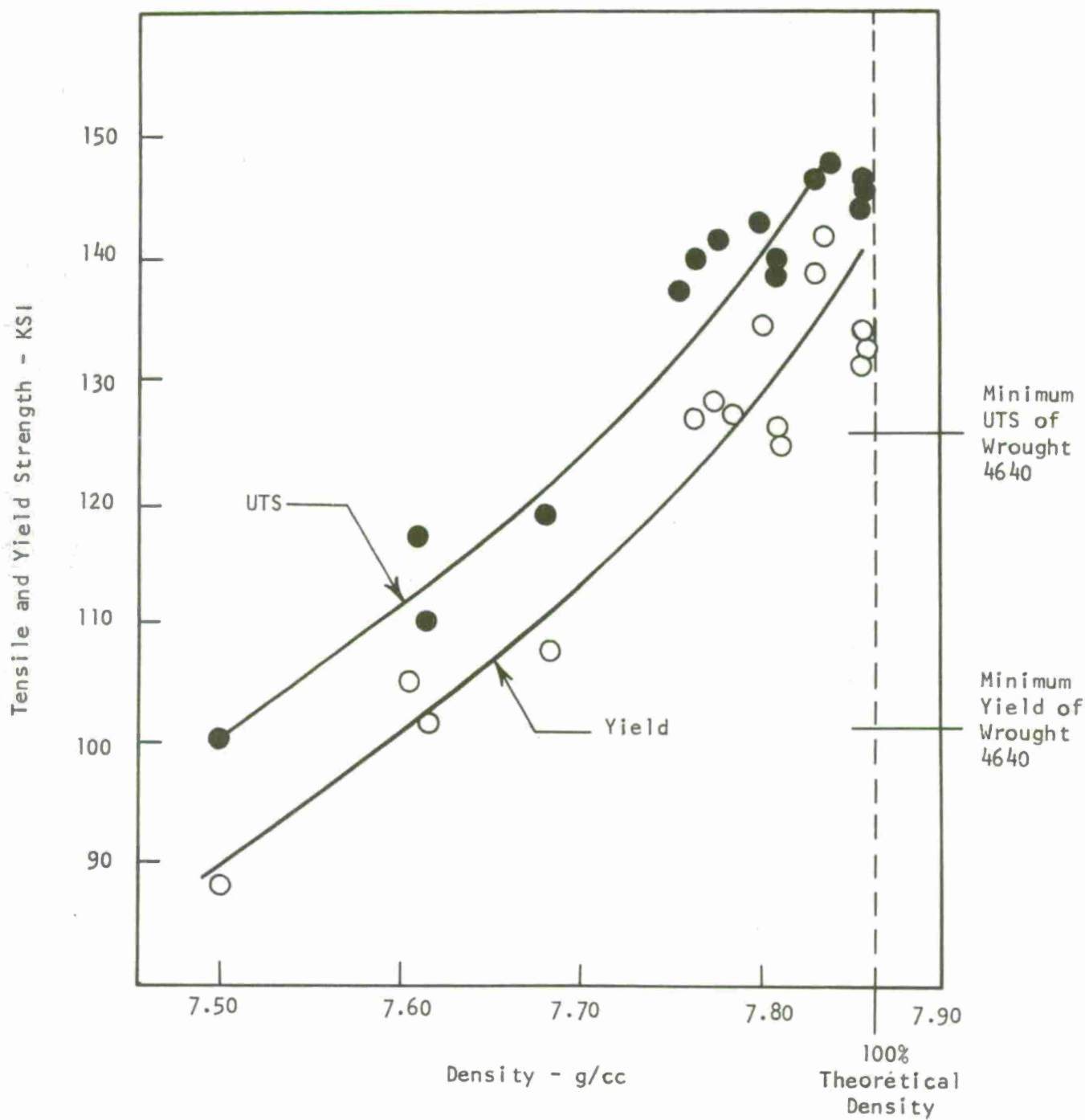and Preform Density Effects on Forged Density

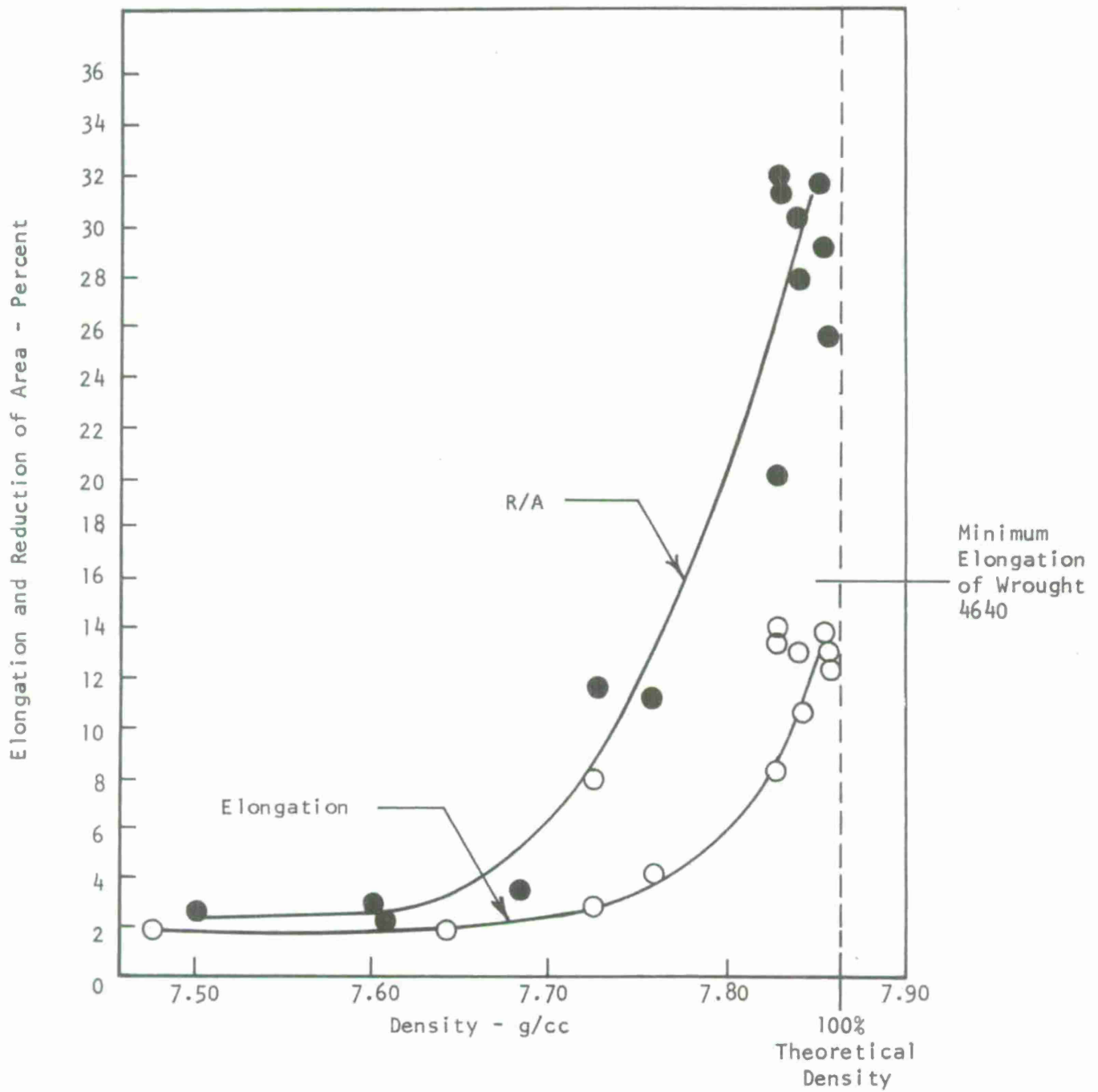FIGURE 11   UTS and Yield Strength vs. Density of
P/M Forgings

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FIGURE 12   Reduction of Area and Elongation vs. Density of
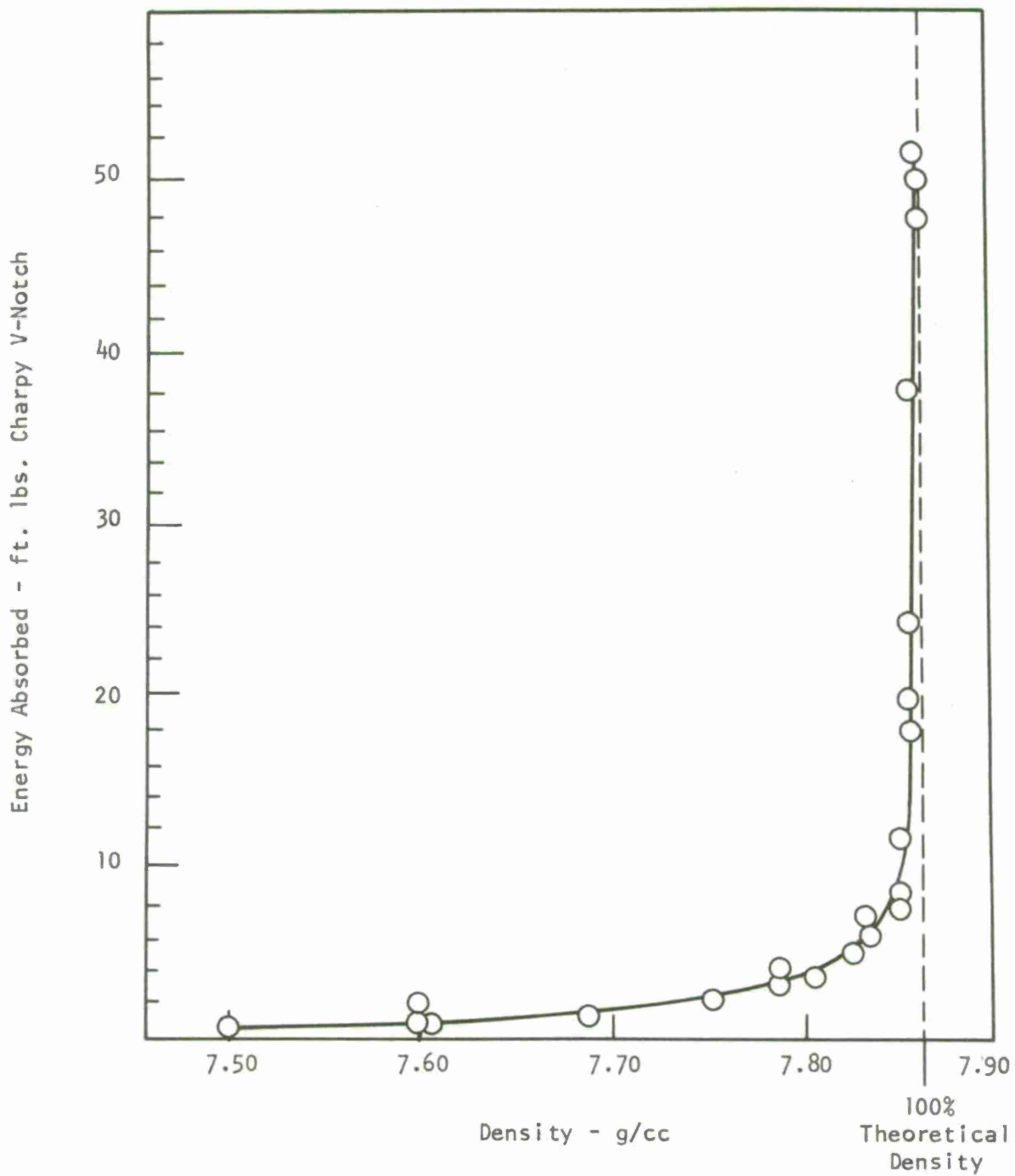   P/M Forgings

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FIGURE 13   Charpy V-Notch Strength of P/M Forgings
                   as a Function of Density

Ductility and impact properties of P/M forgings are sensitive to residual porosity. However, P/M forgings with near theoretical density (99.5 percent plus) have impact strengths and ductilities comparable to bar stock forgings.

An intermediate preform density (6.25 g/cm^3) provided the optimum dynamic properties. High preform density (6.90 g/cm^3) required less strain to achieve full density, however additional work was needed for flow necessary to promote strong bonding at interfaces resulting from pore closures. In the case of low density (5.25 g/cm^3) preforms, most of the work initially is spent closing porosity. Although the amount of deformation given the forging is severe, less lateral flow occurs within the deformed preform in a given forging cycle.

The forging ratio (extent of lateral deformation) affected the forged density, ductility, and impact strength. The "minimum deformation" process (forging ratio 0.95) produced forgings of sufficient densification to meet property specifications (MIL-F-45961). A lower forging ratio of 0.85 resulted in an increase in density, ductility properties, and impact strength. This increase occurs due to the increasing lateral flow which collapses the porosity prevalent in the sintered preform.

FUTURE WORK

The continuation of the program efforts will address two objectives: (1) optimization of sintering parameters and (2) study of the influence of powder characteristics on forged products. Emphasis will be placed on reduction of oxide content and prevention of decarburization in the sintering optimization study. Parameters to be investigated will be gas flow rates, sintering time, and sintering temperature. The effect of particle size distributions on the mechanical and physical properties of P/M steel forgings will be determined in the powder characterization study. Various unimodal and bimodal distributions designed from statistical models will be utilized in this phase of the investigation.

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PROPERTIES OF POWDER METALLURGY STEEL FORGINGS, by
Andrew Crowson, Richard J. Grandzol and Ferrel Anderson

Report R-TR-76-039, May 1976, 28 p. incl. illus. tables,
(DA 1T162105AH84, AMS Code 612105.11.H8400) Unclassified
report.

The effects of processing variables on the mechanical
properties of heat-treated powder metallurgy (P/M) steel
forgings were determined. Three powders, AISI 4600 and
modified AISI 4600 powders blended with graphite to yield
4640 composition, and AISI 4650 powder, were compacted
into preforms and hot forged in a warm, closed die.
Variables studied were preform density, method of lubri-
cation, preform sintering (time, temperature, and atmos-
phere), forging pressure (20 and 40 tsi) and temperature
(1850°F, 2000°F and 2200°F), and forging ratio (0.85 and

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0.95). Relationships between interconnected porosity and total porosity for the various preform densities were determined. High density compacts required higher sintering temperatures due to the restricted mobility of the reducing gases in the pores. Die wall lubrication was comparable to admixed lubrication, and it simplified powder mixing and preform sintering operations. Forgings with densities from 99 to 99.8 percent of theoretical density were attained with a forging pressure of 20 and 40 tsi and preform temperatures of 2000°F and above. At forging conditions, which resulted in forgings with acceptable mechanical properties, complete die fill resulted at a forging ratio of 0.85. The response of P/M forgings to heat treatment was comparable to that for wrought materials, and the resultant tensile and yield strengths were equivalent to the strength values described for wrought 4640 steel in AMS specification 6317B. In addition, ductility and impact properties of P/M forgings with near theoretical density (99.5+ percent) were comparable to bar stock forgings.